Energy Research and Development Division
FINAL PROJECT REPORT

ON-SITE AEROBIC FERMENTATION OF CALIFORNIA CELLULOSIC AGRICULTURAL WASTE INTO BIOFUEL

Prepared for: California Energy Commission
Prepared by: Menon and Associates, Inc.

MENON

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PREFACE

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On-Site Aerobic Fermentation of California Cellulosic Agricultural Waste into Biofuel is the final report for the PIER project (Contract Number PIR-08-049) conducted by Menon and Associates, Inc. The information from this project contributes to Energy Research and Development Division's Transportation Program.

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ABSTRACT

Menon and Associates, Inc. validated a microbial fermentation technique using cellulosic material and its hydrolyzate, a product of hydrolysis, to create triacylglyceride oil as a precursor to renewable biofuels. It chose residues from the two California crops generating the largest revenues, almond hulls and grape pomace (skins, pulp, seeds, and stems). The research team studied and improved microbial culture parameters to use sugars from hulls and pomace as nutrients. The triacylglyceride oil produced by this process was characterized and shown to be well-suited for both biodiesel and hydrocarbon fuels production. The compound was also converted into biodiesel; the transesterification reaction, a process in which the triacylglyceride oil is broken down to ethyl or methyl esters, was optimized to reduce the cost per liter of fuel product. Menon biodiesel meets the American Society for Testing and Materials D6751 specification, meaning the biodiesel is suitable to be used for transportation fuel. Menon combined its cost model for triacylglyceride oil production with an analysis of almond and grape economics to determine the scale at which production of biodiesel on site at the agricultural operation becomes economically preferable to other uses of the agricultural residue. Researchers found that on-farm biodiesel production becomes economically preferable for farms of several hundred to a thousand acres in size. An alternative production scheme that pools the residues from several operations within a bounded geographical area is even more robust economically. The Menon process will benefit Californians by producing petroleum-fungible biodiesel from non-food feedstock , thereby reducing California's dependence on foreign oil, reducing greenhouse gas emissions, and creating new California jobs in green technology.

Keywords: Cellulosic waste, agricultural waste, biofuel, aerobic fermentation, triacylglyceride, biodiesel, renewable diesel.

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EXECUTIVE SUMMARY

Introduction

The development of renewable transportation fuels will reduce dependence upon fossil fuels, increasing U.S. energy independence and reducing greenhouse gas emissions. This project contributes to the goals of California's *State Alternative Fuel Plan* by replacing petroleum (fossil) fuels with alternatives, increasing the proportion of replacement fuels from 9 percent in 2012 to 11 percent in 2017 and 26 percent in 2022. This work can result in a new feedstock – California cellulosic agricultural waste – for production of biodiesel, one of the alternative fuels specified in the plan. The *2012 Bioenergy Action Plan* further specifies that the state should already be producing at least 20 percent of its biofuels within California and mandates that it double the in-state percentage by 2020 and raise it to fully 75 percent of all biofuels by 2050. This project supports the action plan by focusing on agricultural waste feedstock specific to California.

The California Energy Commission's *2009 Integrated Energy Policy Report* sets forth a strategy to maximize the use of alternative fuels. It supports blending biofuels with fossil fuels as well as developing advanced fuel technologies. This project can lead to increased production of both biodiesel and renewable diesel, which can be blended with conventional diesel.

Assembly Bill 32 (Núñez/Pavley, Chapter 488, Statutes of 2006), the Global Warming Solutions Act of 2006, establishes regulatory and market mechanisms to achieve substantial and quantifiable greenhouse gas emissions reductions. This work supports this objective by producing fuel from plant material that isolated carbon from the atmosphere only one or a few years ago, not millions of years ago, as is the case with petroleum. Upon verifying the commercial viability of the technology developed under this effort, Assembly Bill 118 of 2007 (Núñez, Chapter 750), which created the Alternative and Renewable Fuel and Vehicle Technology Program, may provide additional support via its assemblage of grants and loans and other incentives to accelerate market adoption.

Menon and Associates, Inc. has developed a process involving aerobic microbial fermentation of cellulosic material and its hydrolyzate to create triacylglyceride oil as a precursor to renewable biofuels. The triacylglyceride oil can be upgraded in several ways to either biodiesel or to hydrocarbon fuels compatible with the existing petroleum fuel infrastructure. Rather than using starch-based feedstocks like corn or soybeans, the Menon process can use cellulosic agricultural waste, thus eliminating competition with the use of crops for food or fuel. The process also produces high-value coproducts including animal feed; thus, not only does the process not compete with food production, but it converts nonfood materials into animal feed.

The volume of California agricultural waste production that is technically accessible for processing has been estimated to total around 11 million metric tons annually. This waste could yield up to 600 million gallons of fuel, representing 3 percent of the state's annual gasoline and diesel consumption of 20 billion gallons. Incorporating other cellulosic waste streams such as cattle manure, the cellulosic component of municipal solid waste, as well as logging, forestry, and mill wastes adds another 53 million metric tons of potential feedstock to support production of up to 3.2 billion gallons of fuel, or 16 percent of the state's consumption.

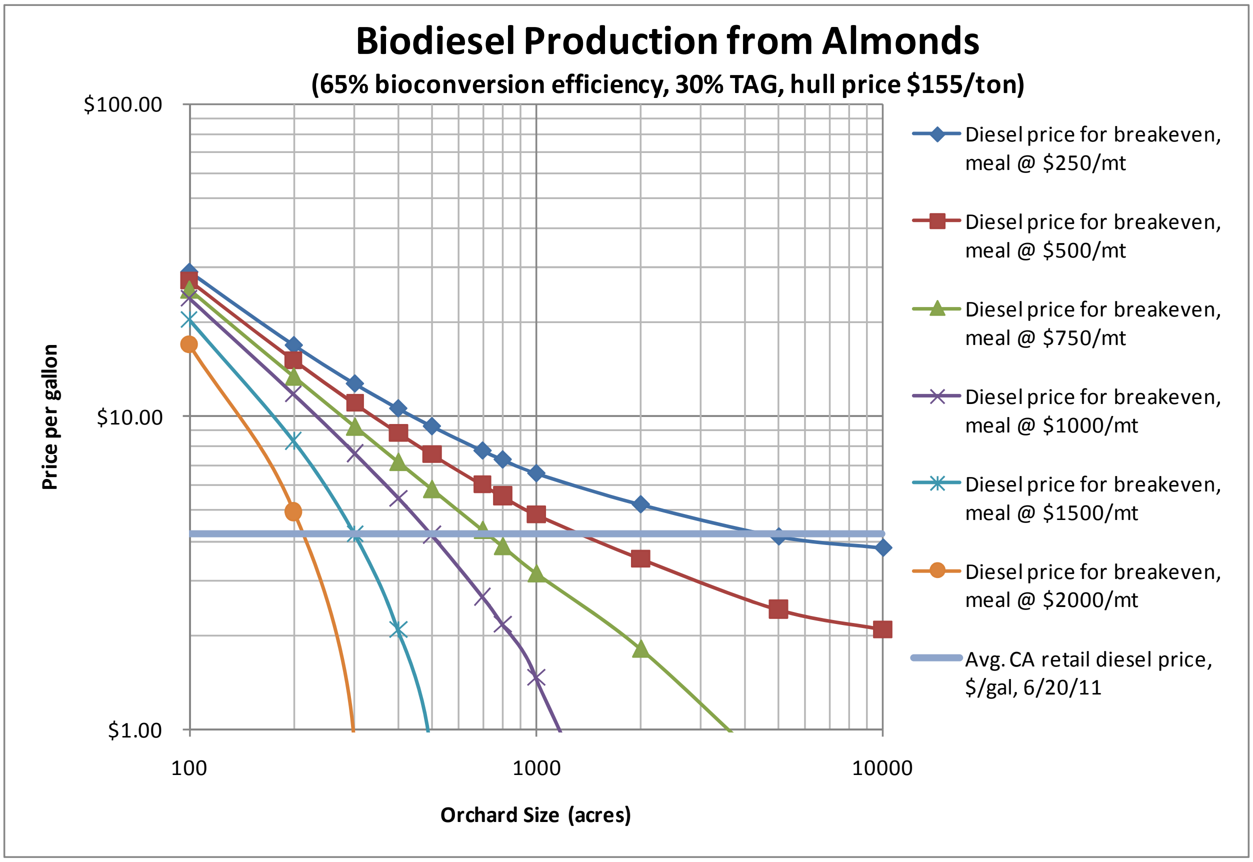
In this project, the Menon staff investigated the use of agricultural residue from the two crops generating the highest agricultural revenue in California: almonds and grapes. Work focused on almond hulls and grape pomace, the skins and pulp of grapes after the juice has been pressed. The economics of biofuel production and other factors, such as the fluctuating cost of diesel fuel, were investigated to evaluate conditions under which farm-scale production of biofuel becomes economically viable. Menon also developed technology transfer and production readiness plans.

Project Outcomes

- Menon demonstrated that almond hulls and grape pomace make economically viable feedstocks and showed the need for pretreatment to break down the cellulose and hemicellulose, a polysaccharide less complex than cellulose, into readily accessible sugars.
- Menon converted its triacylglyceride oil into biodiesel that meets American Society for Testing and Materials D6751 specifications for biodiesel fuel, meaning the biodiesel is suitable for use in vehicles.
- Menon developed an economic model showing that with appropriate pretreatment, almond hulls and grape pomace can become economically viable sources of biofuel at scales of several hundred acres and higher.
- Menon validated that when the biofuel plant power is provided from non-fossil sources, the net greenhouse gas emissions are zero, since the process and later fuel consumption recycle carbon dioxide into the air that had been sequestered from it in the preceding year.
- Menon developed a production readiness plan for its technology and is implementing it.

Figure ES.1 summarizes the cost/benefit calculation for producing biodiesel from pretreated almond hulls. It uses the almond hull cattle feed value as of June 21, 2011. It plots the retail price of diesel necessary for the operation to break even, as a function of the orchard acreage. It also shows the current California retail petroleum diesel price (as of June 20, 2011). The acreage at which each curve crosses the retail price line represents the minimum acreage achieving breakeven. For example, when almond meal is valued at more than $1,000 per metric ton and orchard size exceeds 1,000 acres, the diesel price can be as low as $1.50 per gallon to achieve breakeven. Different curves represent different retail prices obtainable for the biomass co-product of the fermentation process. The higher the co-product value, the smaller the orchard achieving breakeven due to the increased added value compared to unprocessed almond hulls. The biomass has been tested as an animal feed ingredient for aquaculture, and test results support a valuation well in excess of $1,000 per ton. Economies of scale make it even more profitable to centralize a single facility in a growing region, taking feedstock from the local area, rather than distributing smaller plants on each farm or orchard; but even the latter option is viable for larger agricultural operations.

Figure ES-1: Retail Diesel Price Needed to Achieve Breakeven as a Function of Orchard Acreage and Biomass as Animal Food Ingredient Price



Recommendations

This project chose the residues from the two crops generating the largest export revenues in California as feedstocks. Other agricultural waste feedstocks should be investigated, chosen according to the following criteria:

- Maximum fuel production per acre under cultivation
- Geographic concentration of production (to minimize cost of transporting the feedstock to a centralized production facility)
- Maximum differential benefit to the farmer (to maximize willingness to supply agricultural residues for fuel production)

Further work on pretreatment and depolymerization of the cellulosic content is indicated. Since each feedstock has different proportions of cellulose, hemicellulose, lignin, and other structures, the most effective pretreatment varies somewhat from feedstock to feedstock. A commercial facility needs to balance cost-effectiveness for a given feedstock against the expected variation in feedstock properties to arrive at the operational optimum.

Biodiesel is an excellent fuel for on-site manufacture, requiring little infrastructure. The resulting fuel is suited for on-site use in farm equipment (tractors, trucks, and so forth), produce-hauling vehicles, and farm generators. Compared to hydrocarbon fuels (conventionally produced from petroleum), it has drawbacks, including lower energy density and finite shelf life (biodiesel goes rancid if not used by a certain time after manufacture). A centralized facility could profitably convert triacylglyeride oil into hydrocarbon fuels interchangeable with petroleum-based ones. This path should be evaluated for California agricultural waste-based production.

Benefits to California

Successful commercialization of the Menon process of converting agricultural residues to biofuels would provide many benefits to the state:

- Increase the fuel produced in California, using California agricultural waste, thus reducing reliance in imports
- Enhance production of renewable fuels, reducing exploitation of finite fossil resources
- Cut greenhouse gas emissions by reducing consumption of fossil fuels
- Alleviate competition with food production by using non-food resources to produce animal feed as a co-product
- Accelerate job creation in green industries in California, particularly in rural areas near sources of agricultural waste.

CHAPTER 1: EXPERIMENTAL WORK

1.1 Agricultural Waste Feedstocks

Menon concentrated on two crops producing the largest export revenues in California: almonds and grapes. Almond residues are primarily in the form of almond hulls, with almond shells forming a lesser component. The main residue from viticulture is grape pomace: the skins and pulp of grapes after the juice has been pressed. Vine cuttings constitute another residue. Menon’s work focused on almond hulls and grape pomace.

1.2 Cultures

Analyzing the carbon nutrient and mineral content of the feedstocks, Menon adjusted culture parameters to improve productivity of the fermentation process. Initial conditions include added minerals, the inoculum concentration and initial pH. Operating conditions include temperature, steady-state pH, and the like. Experiments were run at the laboratory scale in one-liter cultures in two-liter flasks. Some cultures were also run in a 3000 L bioreactor.

1.3 Triacylglyeride Oil (TAG)

Tricylglyeride oil (TAG) was extracted by a chemical solvent process from the biomass resulting after the fermentation process. Table 1 shows the typical fatty acid composition of the TAG. It is very well-suited for conversion to renewable fuels, with the composition dominated by 16- and 18-carbon acids (palmitic, stearic, oleic and linoleic). This means that, for example, when the acids are transesterified into biodiesel, the resulting esters will have similar chain lengths and enable the biodiesel to meet the corresponding fuel specifications. When the TAG is used as a feedstock for conversion to hydrocarbon fuels, the cracking process will convert it into a range of carbon chain lengths yielding light, gasoline, jet fuel and diesel fractions.

1.4 Biodiesel

Different transesterification reactions were investigated. Two of them, catalyzed by a concentrated acid and by boron trifluoride, failed to complete the conversion of the fatty acids into fatty acid methyl esters (FAME). The other four were successful and achieved varying yields. In comparing cost effectiveness of the different reactions, one accounts for the consumable cost (catalyst) and the energy consumption (reaction temperature and residence time at temperature). Working closely and running tests on small-quantity production and discussions with a large biodiesel manufacturer indicate that the commercial-scale conversion costs will be approximately $0.066 per liter or $0.25 per gallon of biodiesel produced.

Table 1: Fatty Acid Profile of Menon TAG. Cn:m Denotes a Fatty Acid With n Carbon Atoms and m Double Bonds.

Fatty acid	Abundance (wt%)
C12:0 - Lauric Acid	0.011
C14:0 - Myristic Acid	0.29
C15:0 - Pentadecanoic Acid	0.116
C16:0 - Palmitic Acid	20.18
C16:1 - Palmitoleic Acid	0.254
C17:0 - Margaric Acid	0.53
C18:0 - Stearic Acid	16.08
C18:1 - Oleic Acid	26.37
C18:2 - Linoleic Acid	32.2
C18:3 - Linolenic Acid	0.032
C20:0 - Arachic Acid	0.93
C20:1 - Gadaloic Acid	0.085
C20:2 - Eicosadienoic Acid	0.09
C20:3 - Eicosatrienoic Acid	0.05
C21:0 - Heneicosanoic Acid	1.068
C22:0 - Behenic Acid	0.57
C22:1 - Erucic Acid	0.001
C24:0 - Lignoceric Acid	1.11
C24:1 – Nervonic Acid	0.009

Table 2 provides the American Society for Testing and Material (ASTM) test results carried out on Menon biodiesel fuel. It includes the fuel specification and the test result, showing that Menon biodiesel meets or exceeds ASTM D6751 specifications.[1]

4 http://www.astm.org/Standards/D6751.htm

Table 2: ASTM Test Results on Menon Biodiesel (Sample MAA-163-61).

Test Method	Test	Unit	Specification	MAA-163-61
ASTM D 6584-09	Free Glycerin	Mass %	0.020 max	0.013
ASTM D 6584-09	Total Glycerin	Mass %	0.240 max	0.141
ASTM D 2709-96	Water and Sediment	Volume %	0.050 max	0.000
ASTM D 2500-09	Cloud Point	°C	report	12
ASTM D 664-09	Acid Number	mg KOH/g	0.50 max	0.30
ASTM D 4176-04e1	Visual Appearance	1-6	2 max	1
ASTM D 93-08	Flash Point	°C	130 min	173
ASTM D 7039-07	Sulfur	ppm	15 max	12.7
EN 14112-2003	Oxidation Stability	Hours	3 min	5.3
ASTM D 6304-07	KF Moisture	ppm	1000 max	390
ASTM D 6751-09, Annex A1	Cold Soak Filtration	Seconds	360 max	117
ASTM D 4530-07	Carbon Residue	Mass %	0.05 max	<0.01
ASTM D 874-07	Sulfated Ash	Mass %	0.02 max	<0.005
ASTM D 445-09	Kin. Viscosity	mm^2/sec.	1.9-6.0	4.508
ASTM D 613-08	Cetane No.		47 min	51.7
ASTM D 130-04e1	Copper corrosion		No. 3 max	1a
ASTM D 4951-09	Phosphorus	Mass %	<0.001 max	<0.001
ASTM D 1160-06	Distillation, T90	°C	360 max	358
EN 14538-06	Na+K	ppm	5.0 max	<3
EN 14538-06	Ca+Mg	ppm	5.0 max	<2

CHAPTER 2: MODELING

2.1 Economic Model

Menon has used Excel to develop a calculator that predicts process yields and costs. Yields depend on the composition of the feedstock and costs depend, in addition, on the scale of production. Costs are compared to the cost to a farmer of purchasing diesel fuel commercially for operating farm equipment. Revenues from sale of excess fuel and the animal feed co-product are compared to the revenue from sale of unprocessed agricultural waste. Costs are subtracted from revenues to indicate the net profitability of the biofuel operation. Details of the calculator are proprietary to Menon. Note that the calculation does not assume any green credits or subsidies.

Agronomy data for the calculator come from several sources, including the USDA Census of Agriculture[2] and issues of the USDA California Fruit and Nut Report.[3] Grape-specific data is provided by the California Department of Food and Agriculture in the form of periodic reports.[4] Agricultural residue value as animal feed is obtained from wholesale price information compiled by the USDA and updated weekly.[5] Retail diesel fuel prices in California are updated weekly on the California Energy Commission's Energy Almanac site.[6] The U.S. Department of Energy's Energy Information Agency also provides weekly fuel price information.[7]

The acres planted in almonds displays a steady increase over the past decade and a half, increasing by 76 percent, as shown in Figure 1a. The combination of fluctuating yield and fluctuating commodity prices makes the annual revenue fluctuate (Figure 1b). Nevertheless, total crop value has increased by a factor of 2.7 from its 2000 low to the 2009 value.

An important consideration in commercialization of biofuel production from any crop waste is the distribution of acreage by size of individual farm. A commercialization strategy involves

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5 USDA National Agricultural Statistics Service, 2007 Census of Agriculture: California: State and County Data; Document AC-07-A-5; December 2009; accessible at www.agcensus.usda.gov.

6 USDA National Agricultural Statistics Service, California Fruit and Nut Report, issued monthly and accessible at www.nass.usda.gov/ca.

7 California Department of Food and Agriculture: *California Grape Acreage Report, 2009 Crop (April 2010)*, and *California Grape Crush Report, Preliminary 2010 (February 2011)*, both accessible at the USDA National Agricultural Statistics Service site, www.nass.usda.gov/ca.

8 USDA Agricultural Marketing Service, California Wholesale Feedstuff Prices, accessible at http://www.ams.usda.gov/mnreports/jo_gr225.txthttp://www.ams.usda.gov/mnreports/jo_gr225.txt.

9 http://energyalmanac.ca.gov/gasoline/index.html

10 http://www.eia.gov/oog/info/wohdp/diesel.asp

reaching agreements with one or more larger producers first, and then bringing in others when the value proposition becomes clear to all. Market penetration is most efficient when dealing with the largest producers, so the distribution of farm size provides a metric. Figure 2a shows the total number of almond orchards against the maximum acreage in each bin, while Figure 2b shows the total acreage farmed per bin. It is clear that the acreage is dominated by a few large producers. Figure 3 bears this out, plotting the number of farms as a function of the percentage of total acreage in the state. It shows that about 320 orchards (4.9 percent of the total of 6,474 orchards) account for 50 percent of the total production; of these, 290 are 500 acres or larger.

The conclusions are largely similar in the case of grapes. Figures 4 and 5 present the analogous data. About 360 vineyards (3.1 percent of the total of 11,623) account for 50 percent of total production, with 306 of these vineyards over 500 acres in size.

Figure 1: 1a: Total Acres in Almond Production; 1b: Total Annual Production Value.

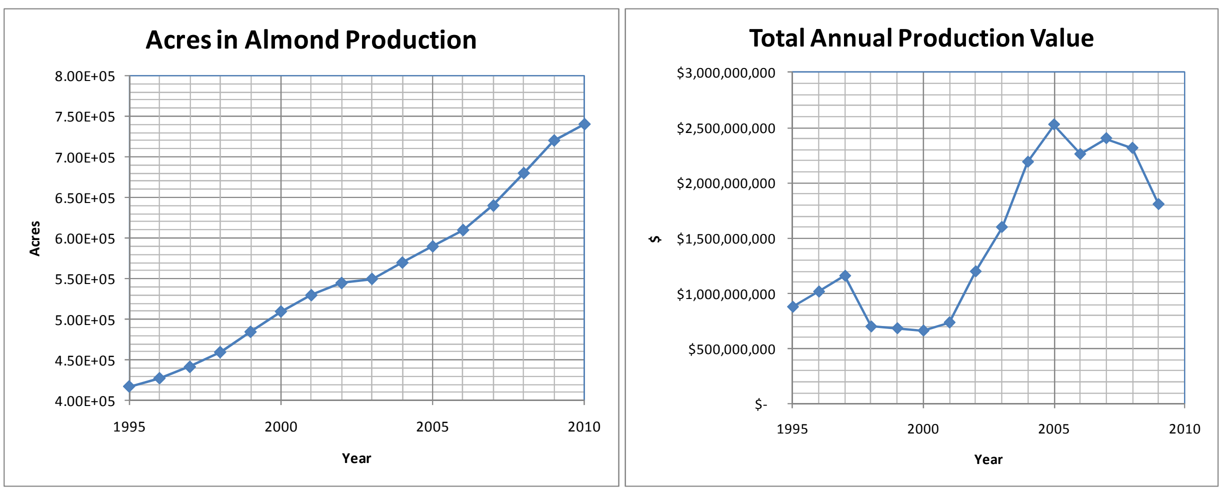


Figure 2: 2a: Histogram of Number of Orchards Versus Maximum Size Bin; 2b: Histogram of Total Acreage in Cultivation Versus Maximum Size Bin

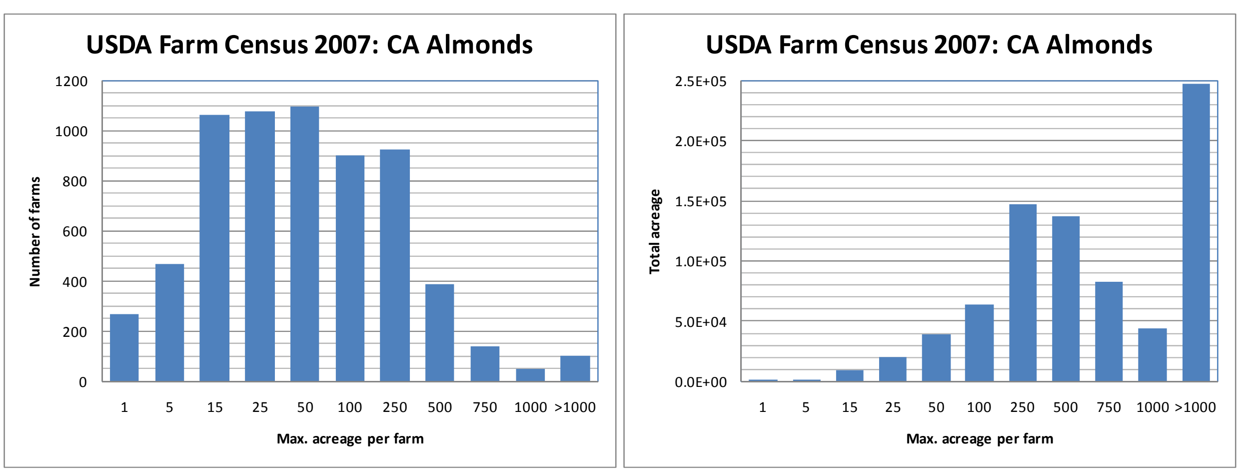


Figure 3: Number of Orchards Needed to Cover a Given Percentage of the Total Acreage Under Cultivation

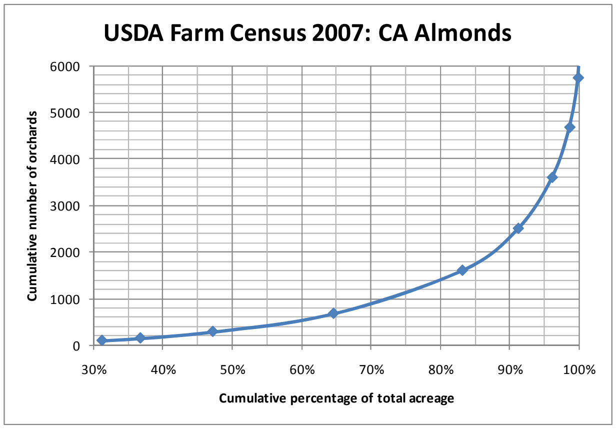
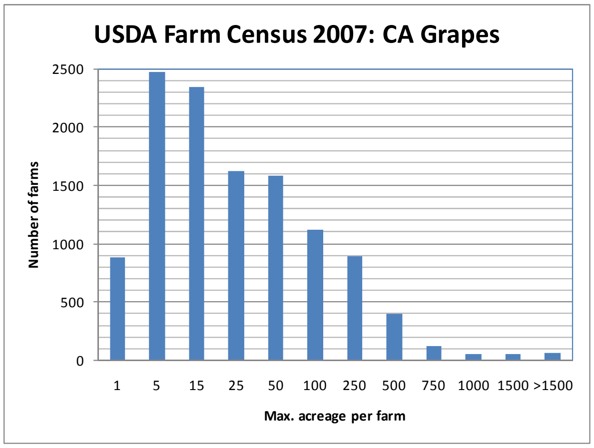


Figure 4: 4a: Histogram of Number of Vineyards Versus Maximum Size Bin; 4b: Histogram of Total Acreage in Cultivation Versus Maximum Size Bin.



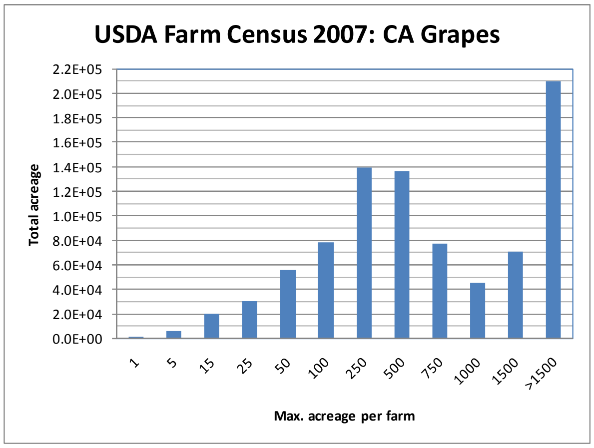
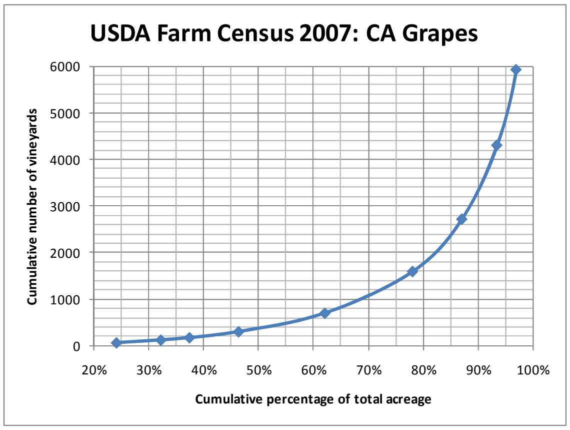


Figure 5: Number of Vineyards Needed to Cover a Given Percentage of the Total Acreage Under Cultivation.



Another important component of farm production economics is the fluctuating cost of key commodities. One key commodity is diesel fuel needed to operate the agricultural enterprise; as its price fluctuates, so does the economic benefit of producing biodiesel on-site. Another is the price the farmer can get for selling his or her agricultural waste as animal feed. Both grape pomace and almond hulls are sold as dairy cattle feed in California. The latest price for grape pomace (as of fall 2010) was $72 per ton. The latest price for almond hulls (June 2011) is $165 per ton. Since almond hulls are available as a feed year-round, a time series of prices can be derived from the weekly California Feedstuff Report of the USDA Agricultural Marketing Service. Figure 6 shows average U.S. on-highway diesel retail prices for the last two and a half years; California prices are reliably 5 percent or so higher than the U.S. average. Figure 7 shows the weekly almond hull price history for the last three and a half years. Diesel has fluctuated by over a factor of 2 in price from the recession low of March 2009 to the recent high of May 2011. Almond hull prices fluctuate even more, by a factor of 2.6 from the recession low of March 2009 to the pre-recession high of August 2008. Economic modeling must consider such fluctuations.

Figure 6: U.S. Retail Diesel Fuel Price Fluctuations, 1/2009 Through 7/2011

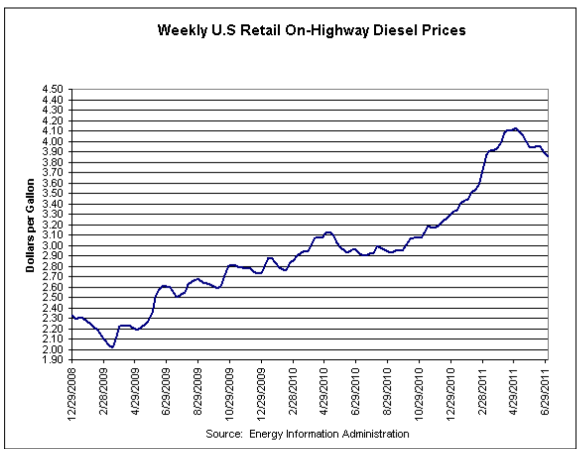
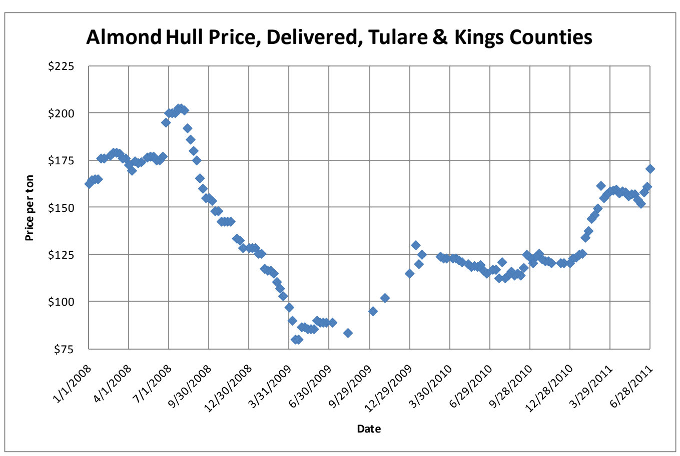


Figure 7: Almond Hull Price Fluctuations, 1/2008 Through 7/2011



The cost/yield predictor was combined with farm statistics and plant design costs into an integrated calculator to model the economics of on-site biodiesel production at the orchard or vineyard. Economic cost or benefit is compared to a baseline operation wherein the farmer purchases petroleum diesel at retail prices to operate machinery (according to the 2007 USDA Census of Agriculture, the average California fruit/nut farmer uses about 33 gallons per acre annually) and sells the agricultural waste as cattle feed. The cost of producing the biodiesel is weighed against the cost of purchasing petroleum diesel and the increased value of the animal feed co-product, compared to the unprocessed agricultural waste. The calculation takes into account that glycerol, a major byproduct of biodiesel manufacture, can be recycled as a carbon source in the microbial fermentation, effectively increasing the yield of biodiesel per unit mass of agricultural waste.

Figure 8 summarizes the cost/benefit calculation for producing biodiesel from almond hulls. It uses the almond hull cattle feed value (as of June 21, 2011). On the ordinate, it plots the retail price of diesel necessary for the operation to break even, as a function of the orchard acreage. It also shows the current California retail petroleum diesel price (as of June 20, 2011). The acreage at which each curve crosses the retail price line represents the minimum acreage achieving breakeven. Different curves represent different retail prices obtainable for the biomass co-product of the fermentation process. The higher the co-product value, the smaller the orchard achieving breakeven because of the increased added value compared to unprocessed almond hulls. Note that the biomass has been tested as an animal feed ingredient, and test results support a valuation well in excess of $1,000 per ton.

Figure 8: Retail Diesel Price Needed to Achieve Breakeven as a Function of Orchard Acreage and Biomass as Animal Food Ingredient Price

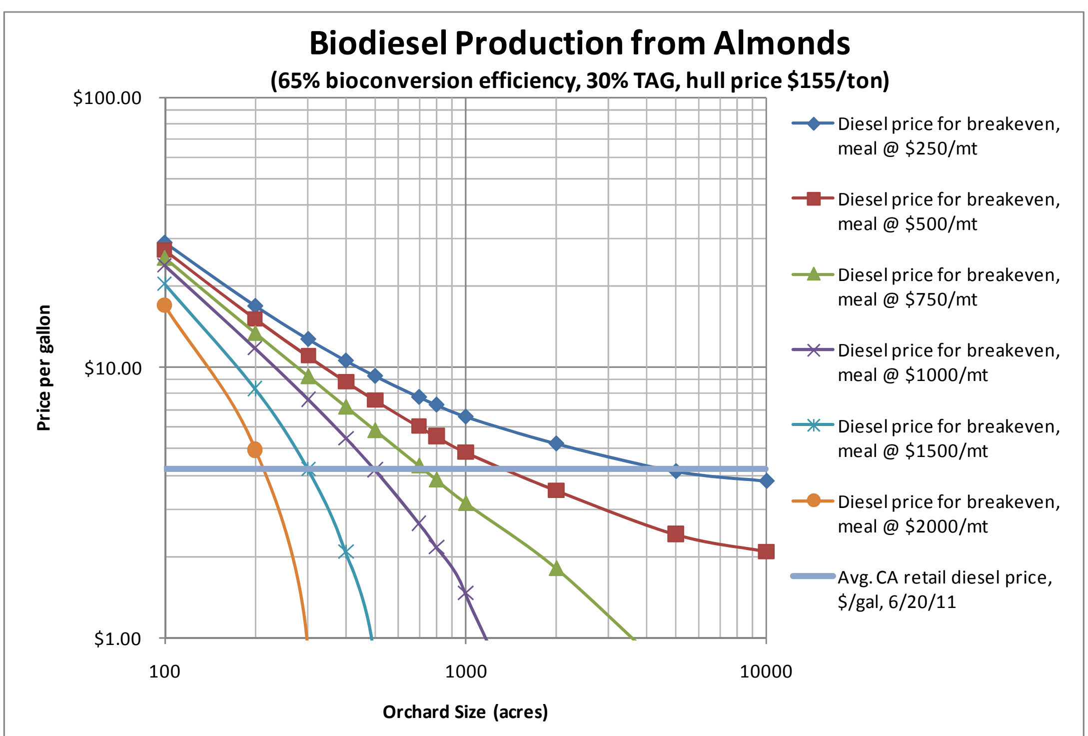


Figure 9 shows the effect of bioconversion process efficiency on the breakeven. The lower the price of the biomass, the more crucial it is to maintain lipid production (for conversion to biodiesel). At sufficiently high feed ingredient prices, the effect disappears and the process becomes immune to variations in lipid productivity.

Figure 10 shows the effect of retail petroleum diesel prices and feed ingredient pricing on breakeven acreage. The less expensive petroleum diesel is, the more critical a feed ingredient price becomes for economic sustainability. At high feed ingredient values, the economics are only marginally affected by the price of diesel.

Figure 11 shows that the price of unprocessed almond hulls as cattle feed has the greatest impact on economic sustainability. Breakeven acreage rapidly increases as the ratio of feed ingredient price to almond hull price approaches unity. The range of almond hull prices in Figure 11 somewhat exceeds the actual historical price volatility shown in Figure 7.

Figure 9: Breakeven Orchard Acreage as a Function of Animal Feed Price for Different Lipid Productivities.

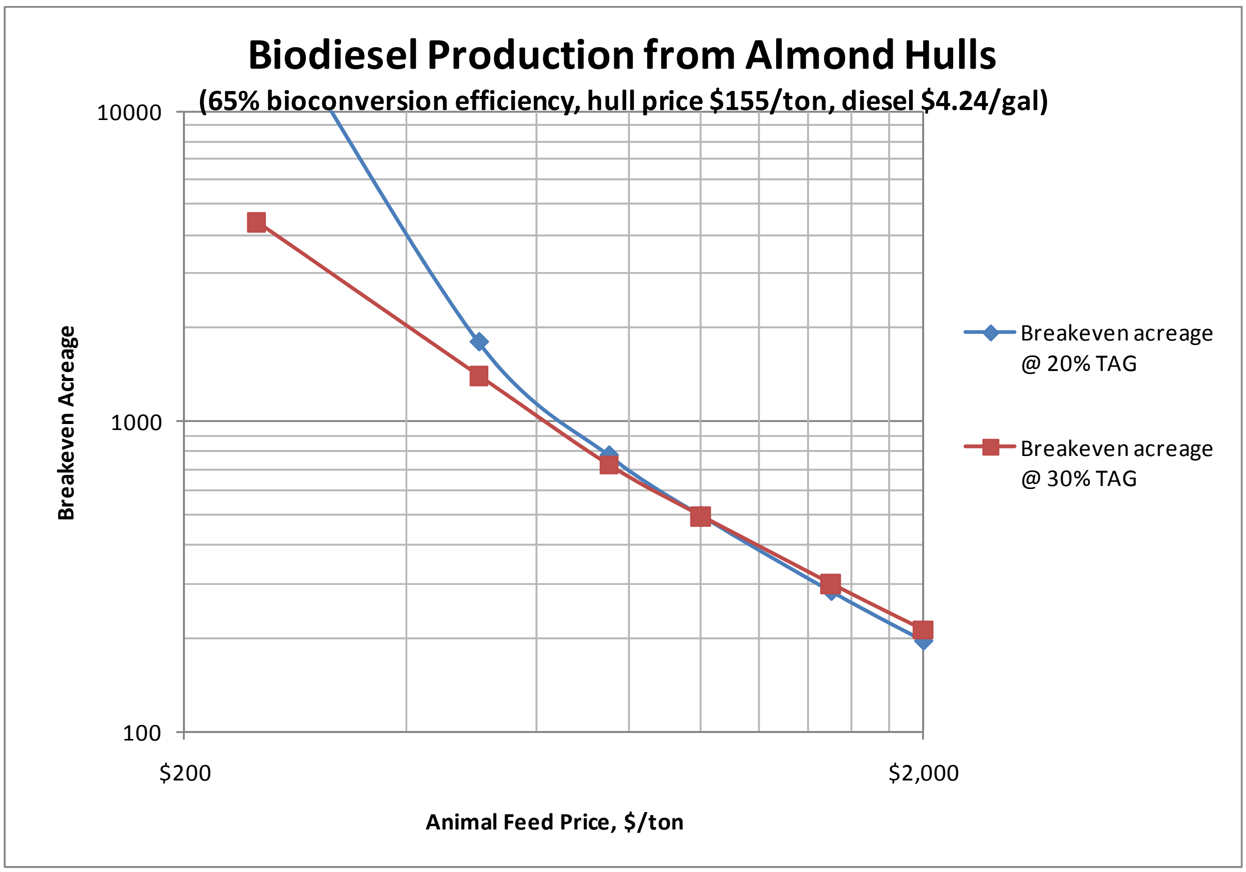


Figure 10: Breakeven Orchard Acreage as a Function of Animal Feed Price for a Range of Petroleum Diesel Prices.

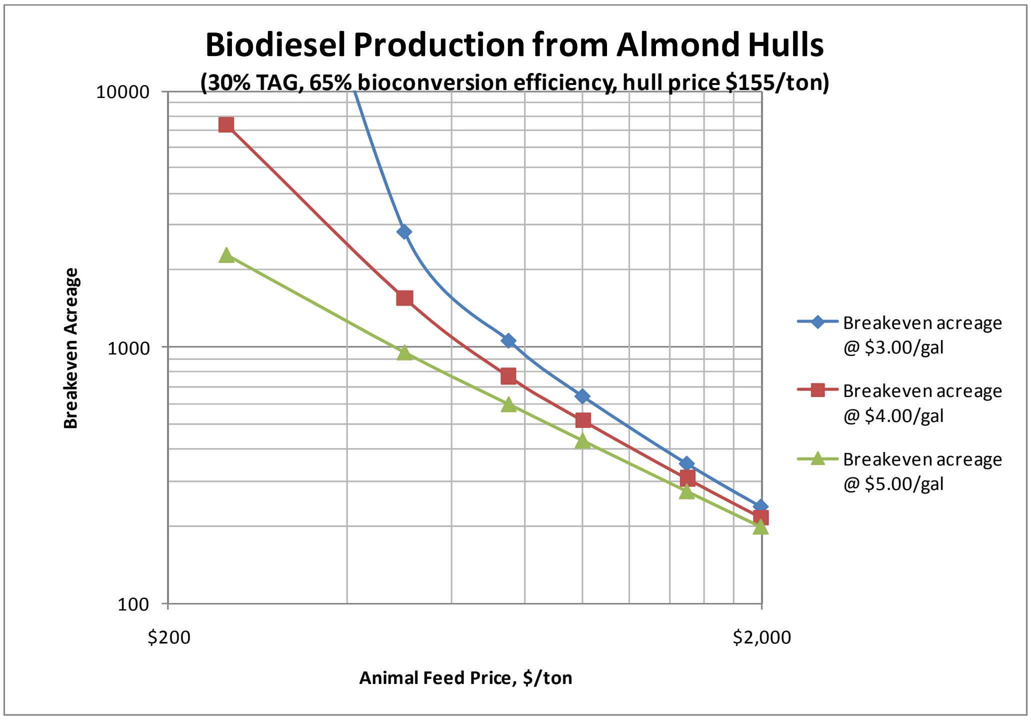
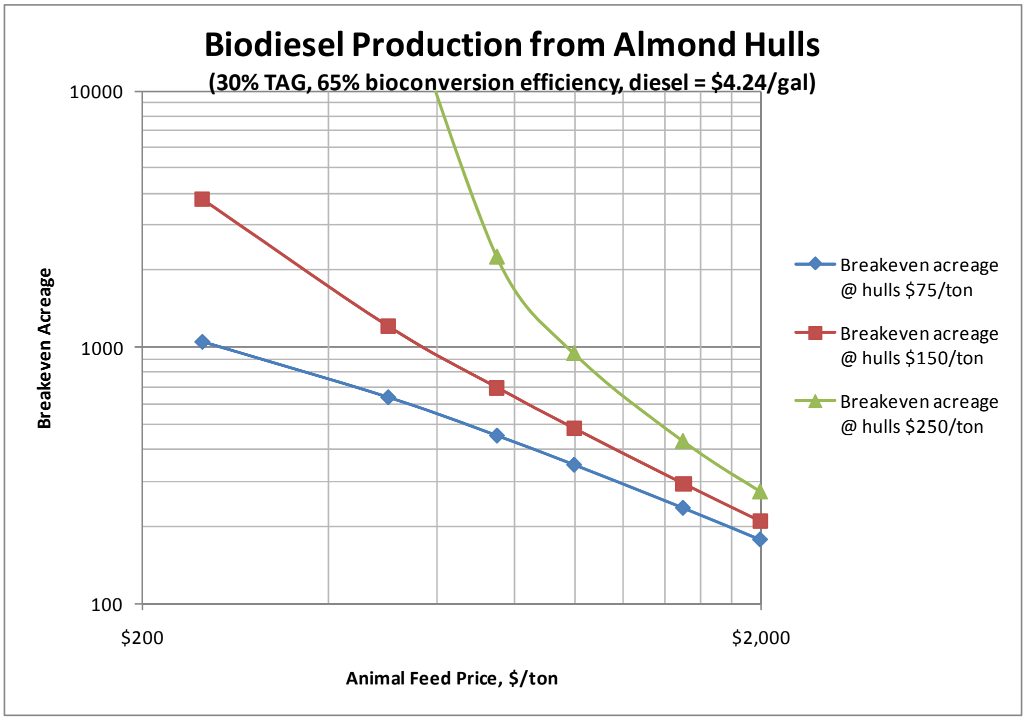


Figure 11: Breakeven Orchard Acreage as a Function of Animal Feed Price for a Range of Unprocessed Almond Hull Prices.



Modeling of grape pomace leads to qualitatively similar conclusions, as summarized in Figure 12. The main differences are (1) smaller output of waste per acre (1463 kg/acre of pomace compared to 4227 kg/acre of almond hulls) and (2) a lower cattle feed value for grape pomace ($72/ton compared to $155/ton). The two differences tend to cancel each other: the smaller output means that fermentation facilities are smaller for vineyards than for orchards of the same size, so cost per unit production is higher; but the lower value of the unprocessed waste means that one is competing with smaller baseline revenue.

Figure 12: Retail Diesel Price Needed to Achieve Breakeven as a Function of Vineyard Acreage and Animal Feed Price.

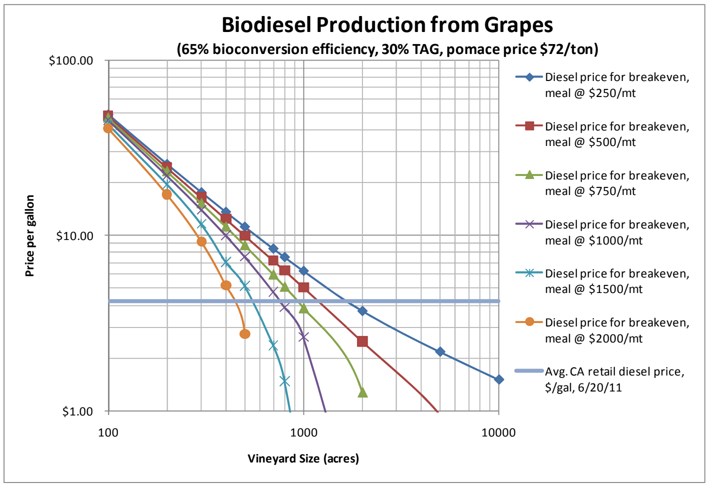
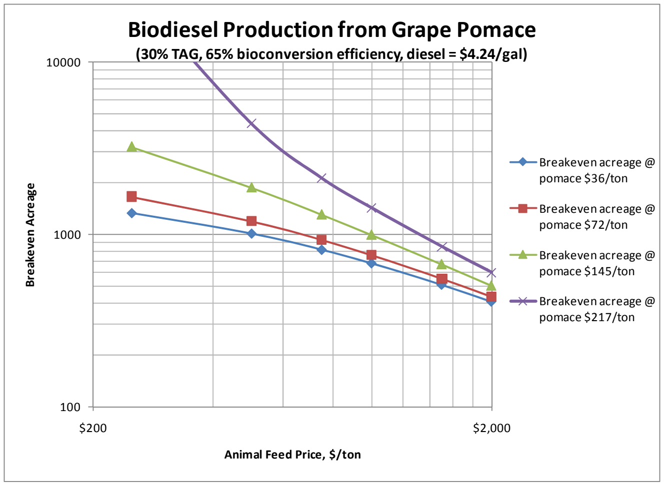


Figure 13 presents the grape pomace equivalent of Figure 11.

Figure 13: Breakeven Vineyard Acreage as a Function of Animal Feed Price for a Range of Unprocessed Grape Pomace Prices



In conclusion, the economic model suggests that on-site biodiesel production can be profitable to the farmer under most circumstances, especially on larger-scale orchards or vineyards (of the order of 1000 acres). Production facilities based not directly on an individual farm but centrally in a region of intense cultivation are virtually guaranteed to operate profitably by virtue of drawing on much larger acreage and taking advantages of economies of scale.

2.2 Energy Balance and Environmental Model

An energy balance model has been developed and implemented in Excel. It allows one to enter input values for feedstock (amounts and energy densities) and other consumables (for example, methanol needed for transesterification of TAG to biodiesel) and outputs process energy efficiencies. Results show that when one takes the energy content of the biodiesel and animal meal produced as main products of the process, the energy efficiency exceeds 50 percent.

An Excel calculator model was prepared to numerically evaluate the environmental impacts, using the Menon biodiesel process as a basis. Environmental effects were categorized as resource usage, energy consumption, and non-recycled effluents. The model starts with a number of empirical parameters and adjustable assumptions, and then calculates the "inputs" and "outputs" for each step of the process. Empirical parameters were drawn primarily from the flask-scale laboratory studies at Menon, which are ongoing, as well as anticipated engineering results from the planned scale-up program. User-adjustable assumptions include process parameters, expected performance values, and "switches" that select different process options.

Resource usage includes the cellulosic feedstock, water, and reagents; energy usage includes gas and electricity; and effluent generation includes CO_2, final solids (if not recycled), and any escaped solvents, plus combustion products if on-site power generation is assumed. Many of the process effluents have significant value and would likely be recycled or sold as byproducts rather than appearing as pollutants. Finally, the environmental impact of diesel fuel obtained by petroleum refining was compared to the biofuels case.

The model includes a number of recycling options. Glycerol from biodiesel production can be recycled as feed. The fermentation broth filtrate can be recycled *N* times (for a total of *N*+1 fermentation runs) before it is released. Solvents, cleaning water, and recoverable reagents are recovered according to user-specified recycling fractions.

Likewise, the model includes multiple options regarding energy usage. Process heat may come from purchased gas, while purchased electricity may be assumed for pumps and motors and the like. In this case, carbon footprint is calculated using Pacific Gas & Electric's values of 11.7 lbs of CO_2 produced per therm of natural gas and 0.575 lbs of CO_2 emitted per kilowatt hour of electric energy.[8] (The latter value represents the California average for electricity production in 2009.) However the user can choose to invoke on-site process heat and/or electricity generation through combustion of green waste. In the model, green waste is assumed to be almond hull

11 See PG&E's carbon calculator: http://www.pge.com/myhome/environment/calculator/assumptions.shtml.

solids after extraction of sugars. Note that all the on-site process heat and electricity can be provided by burning only 8 percent of the residual almond solids.

Since the agricultural model posited in this effort is for on-site production at a farm, vineyard or orchard, the model assumes no fuel expenditure in transporting the agricultural residue to the production facility. The on-farm transport costs are incurred in the ordinary routine of food production, and co-locating the plant adds negligibly to the transport.

The model was used to calculate the environmental impact of a system to produce biodiesel from almond hulls from a 5000 acre orchard. The model assumptions were drawn from experimental results at the flask scale. Engineering performance parameters were estimated for an *N*-th plant site. The results were compared to the environmental impact of petroleum-derived vehicle fuel. The impact of oil well drilling, oil production, refinery operations, and fuel combustion were considered separately. The vehicle fuel products of all US refineries were totaled for the model year of 2005. Likewise the energy usage and effluents were totaled for domestic refineries. Each pollutant was then normalized per kilogram of fuel (jet + diesel + gasoline + bunker) and tabulated along with the corresponding value for the biofuels case. The following items summarize the biofuel and petroleum environmental impacts based on the resources used, energy used, and effluents released. Results are derived from the almond farm case (biodiesel) or the average US refinery total for 2005 (petroleum), and are normalized per kilogram of vehicle fuel product.

The primary results are as follows:

1. SPILLS: Petroleum oil spills produce long-term toxic deposits in the environment that degrade slowly if at all, and produce extensive damage. Biodiesel, on the other hand, is readily consumed by indigenous biological processes, typically in 2 weeks or less. Therefore the effect of a biodiesel spill is expected to be much less harmful to the environment than that of an equal-volume spill of crude oil.

2. WATER: The biofuel process uses more water than the petroleum case (per kg of fuel product); however the filtrate effluent from the biofuel process can be used for irrigation, whereas the toxic refinery wastewater cannot. Tests at the flask level have demonstrated that culture water can be recycled at least four times. Larger-scale tests to recycle the water completely are ongoing in parallel to using the filtrate for various purposes.

3. VOC, SO_2, NO_X: The biofuel process generates less VOC than the petroleum case (per kg of fuel product) as a result of improved solvent capture, less NO_X than the petroleum case due to advanced burner design, and less SO_2 than the petroleum case since the sulfur content in green waste is typically very low.

4. CO_2: A valid CO_2 comparison between biodiesel and petroleum fuel requires comprehensive accounting of the carbon flow. In the case of biofuel from agricultural waste, the carbon in the fuel was drawn from the atmosphere photosynthetically. A portion of the captured carbon is released as CO_2 by fermentation reactions, a second

portion is released if some of the waste is combusted on-site, and a third portion is released when the biodiesel is consumed. In the end, all of the photosynthetic carbon is returned to the atmosphere, and the net change in atmospheric CO_2 is zero. (In the event that process power is purchased rather than produced on-site, there is a net CO_2 change; this is considered below.) Furthermore, it is important to recognize that if the agricultural waste had not been processed into biofuel, the material would have decomposed naturally. Such decomposition generates the same amount of CO_2, which is again exactly canceled by the initial withdrawal of carbon from the atmosphere. (Natural decomposition may also generate more-harmful greenhouse gases such as CH_4. The biofuel process generates no such effluents.) The petroleum case, on the other hand, releases CO_2 that was exclusively derived from fossil carbon. Fossil-derived CO_2 is produced during petroleum processing, and by burning a portion of the stream for process heat, and by combustion of the fuel product. All of these fossil-derived CO_2 effluents add to the atmospheric burden of greenhouse gases, with no compensating withdrawal. In addition, any escaping flue gas or methane contributes further greenhouse gases.

Table 3 compares the Menon almond hull-based biodiesel process to petroleum diesel, presenting both absolute production (for a 5000-acre orchard and for all US petroleum refineries in 2005) as well as production per unit mass of fuel product. It assumes that the biofuel plant produces all required heat and electricity on-site, via combustion of almond hull residues. The Table is organized into horizontal blocks representing different categories. The top row presents the total fuel product volume. The next two rows list the amount of biomass and/or fossil fuel consumed by the production process. The following two rows calculate the mass of CO_2 produced by each process, dividing it into recycled photosynthetic CO_2 and fossil CO_2. The next two rows present the CO_2 emissions resulting from using the fuel produced, and the two following that total the CO_2 emissions for both production and utilization steps, always keeping the recycled CO_2 separate from fossil CO_2. The remaining rows tabulate other environmental impacts not related to CO_2.

Table 3: Comparison of Environmental Impact of Menon Biodiesel Process and Petroleum Diesel, Assuming All Biofuel Process Energy Is Generated On-Site Via Combustion of Almond Hull Residues

	BIOFUELS CASE				PETROLEUM CASE			
Factor	Almond Orchard model		Relative to fuel product		US refineries		Relative to fuel product	
Annual total vehicle fuel product	775,449	kg/year			567,000,000,000	kg/year		
Biomass combustion (a)	805,030	kg/year	1.04	w/w	-	kg/year	0.00	w/w
Fossil fuel combustion (b)	-	kg/year	0.00	w/w	69,000,000,000	kg/year	0.12	w/w
Production CO2 - photosynthetic (c)	**6,520,706**	**kg/year**	**8.41**	**w/w**	**-**	**kg/year**	**0**	**w/w**
Production CO2 - fossil (d)	**-**	**kg/year**	**0.00**	**w/w**	**510,000,000,000**	**kg/year**	**0.90**	**w/w**
Fuel usage CO2 - photosynthetic	**2,186,765**	**kg/year**	**2.82**	**w/w**	**-**	**kg/year**	**0**	**w/w**
Fuel usage CO2 - fossil	**-**	**kg/year**	**0**	**w/w**	**1,791,720,000,000**	**kg/year**	**3.16**	**w/w**
TOTAL CO2 - photosynthetic	**8,707,471**	**kg/year**	**11.23**	**w/w**	**-**	**kg/year**	**0**	**w/w**
TOTAL CO2 - fossil	**-**	**kg/year**	**0.00**	**w/w**	**2,301,720,000,000**	**kg/year**	**4.06**	**w/w**
Electric power (purchased)	-	KWH/year	0.00	KWH/kg	47,300,000,000	KWH/year	0.08	KWH/kg
Oil spills (normalized to worldwide)	-	kg/year	0	w/w	41,016,949	kg/year	0.0001	w/w
VOC released	186	kg/year	0.0002	w/w	1,100,000,000	kg/year	0.0019	w/w
NOx released	81	kg/year	0.0001	w/w	180,000,000	kg/year	0.0003	w/w
SO2 released	-	kg/year	0.0000	w/w	210,000,000	kg/year	0.0004	w/w
Water used by process	16,628,224	kg/year	21.44	w/w	2,145,000,000,000	kg/year	3.78	w/w

NOTES:
(a) represents spent hulls burned
(b) represents natural gas burned in biofuels case
(c) CO2 released in fermentation and/or combustion of ag waste feedstock
(d) CO2 released in electric and natural gas consumption

Table 4 presents the same calculations, but under the assumption that *none* of the on-site power in the biofuel plant is locally produced, but that all of it is purchased as natural gas or electricity from the grid. It shows that even in this worst-case (and rather unlikely) implementation, the fuel-normalized fossil CO_2 emission of the biofuels case is about half that of petroleum.

Table 4: Comparison of Environmental Impact of Menon Biodiesel Process and Petroleum Diesel, Assuming All Biofuel Process Energy Is Generated Via Purchase of Natural Gas and Grid Electricity

	BIOFUELS CASE				PETROLEUM CASE			
Factor	Almond Orchard model		Relative to fuel product		US refineries		Relative to fuel product	
Annual total vehicle fuel product	775,449	kg/year			567,000,000,000	kg/year		
Biomass combustion (a)	-	kg/year	0.00	w/w	-	kg/year	0.00	w/w
Fossil fuel combustion (b)	206,832	kg/year	0.27	w/w	69,000,000,000	kg/year	0.12	w/w
Production CO2 - photosynthetic (c)	**4,910,645**	**kg/year**	**6.33**	**w/w**	**-**	**kg/year**	**0**	**w/w**
Production CO2 - fossil (d)	**1,584,643**	**kg/year**	**2.04**	**w/w**	**510,000,000,000**	**kg/year**	**0.90**	**w/w**
Fuel usage CO2 - photosynthetic	**2,186,765**	**kg/year**	**2.82**	**w/w**	**-**	**kg/year**	**0**	**w/w**
Fuel usage CO2 - fossil	**-**	**kg/year**	**0**	**w/w**	**1,791,720,000,000**	**kg/year**	**3.16**	**w/w**
TOTAL CO2 - photosynthetic	**7,097,410**	**kg/year**	**9.15**	**w/w**	**-**	**kg/year**	**0**	**w/w**
TOTAL CO2 - fossil	**1,584,643**	**kg/year**	**2.04**	**w/w**	**2,301,720,000,000**	**kg/year**	**4.06**	**w/w**
Electric power (purchased)	4,169,121	KWH/year	5.38	KWH/kg	47,300,000,000	KWH/year	0.08	KWH/kg
Oil spills (normalized to worldwide)	-	kg/year	0	w/w	41,016,949	kg/year	0.0001	w/w
VOC released	186	kg/year	0.0002	w/w	1,100,000,000	kg/year	0.0019	w/w
NOx released	-	kg/year	0.0000	w/w	180,000,000	kg/year	0.0003	w/w
SO2 released	-	kg/year	0.0000	w/w	210,000,000	kg/year	0.0004	w/w
Water used by process	16,628,224	kg/year	21.44	w/w	2,145,000,000,000	kg/year	3.78	w/w

NOTES:
(a) represents spent hulls burned
(b) represents natural gas burned in biofuels case
(c) CO2 released in fermentation and/or combustion of ag waste feedstock
(d) CO2 released in electric and natural gas consumption

CHAPTER 3: PLANNING

3.1 Technology Transfer Plan

The Menon Technology Transfer Plan supports its plan to commercialize the technology. The first priority is, accordingly, to protect the intellectual property (IP) related to the process. Some IP is protected via patent applications that are eventually published by the US Patent and Trademark Office (USPTO). Some of this information can later be published once the patent application is filed, and other information is only published in refereed scientific or other journals (such as trade journals) after the USPTO has itself published the application. Such choices balance the need for publication against the need to maintain a technological lead over industry competitors.

Other IP, such as the feedstock-specific work funded by the present grant, is typically protected as trade secrets and disclosed to decision-makers under the protection of nondisclosure agreements. Some such information is not obvious or broadly known, but not necessarily inventive, as defined in patent law. Other information may be inventive, but too narrow in application to justify the cost of patenting it. Thus, detailed performance parameters and economics associated with almond hulls and grape pomace are disclosed to the sponsoring agency and to potential partners in the commercialization of the Menon process. Disclosures are made – when they are made at all – under protection of nondisclosure agreements to prevent further dissemination of the information.

To date, Menon has obtained first-round debt financing for infrastructure of its research and engineering-scale development facility (called the Innovation Center), as well as for working capital. It is in active discussions on subsequent financing rounds, initially focused overseas but projected to include a domestic (California) component in the near future.

Knowledge gained in this project relates to the specific use of California agricultural waste as a feedstock for production of fuel and co-products. Properties of the fuel and co-products are being, and will continue to be, disseminated in a variety of forms. Examples include conferences and workshops, as well as disclosures to potential customers for the products.

Specifically, Menon has disclosed its triacylglyceride (TAG) oil properties to a large biodiesel producer and, in return, received its interest to purchase the TAG oil for conversion to biodiesel. This came about through close collaboration between Menon and the interested party, wherein the biodiesel producer converted Menon TAG of different stages of purification into biodiesel.

The commercial viability of biofuel production universally depends on the ability to sell co-products of the process. Process co-products play the same role as specialty chemicals produced as co-products by petroleum refineries. Where fuels are commodity items and margins are tight, specialty chemicals sold at higher margins are often key to refinery profitability. In the case of the Menon process, it has been found that the microbial cells after extraction of the TAG (the so-called "spent microbial biomass") can serve as a high-value animal feed ingredient.

Nutritional properties of the animal feed co-product have been evaluated via aquaculture feed trials conducted, at Menon expense, by an accredited independent laboratory. Tests were performed on a commercially farmed prawn species. The prawns exhibited weight gain comparable to those fed the control feed formulation, a premium commercial feed. Survivability results were greater than those of the control group by a statistically significant margin. These properties indicate that the co-product can command a premium price for aquaculture. Results have been shared with a number of firms involved in preparation of aquaculture feeds. Letters of interest from several such firms demonstrate their interest in purchasing the Menon feed ingredient when production reaches suitable scale. An initial market analysis supports a price of $1,000 per metric ton, or even higher.

A necessary step in commercializing the animal feed co-product, specified by the U.S. Food and Drug Administration, is to publish a paper describing the feed, its nutritional properties and the results of animal feed trials. The paper must be published in a public, refereed journal, after which Menon is free to certify the feed ingredient as safe and effective. This process is presently under way.

The fact that Menon biodiesel meets all ASTM D6751 specifications has been shared in conference presentations – for example, at the Cleantech Workshop and Action Summit[9] – and this activity will continue (for example, at the Association for the Advancement of Industrial Crops annual meeting[10]). As Menon also demonstrates hydrocarbon fuels (renewable diesel, gasoline and jet fuels compatible with their petroleum equivalents) developed from the lipids produced by its process, these results will also be disseminated at conferences, for example at the Commercial Aviation Alternative Fuels Initiative (CAAFI) general meeting.[11]

The general principles of Menon's Technology Transfer plans can be expressed as follows:

- As new IP is created, determine whether it is desirable to patent it. If so, create patent applications and file them promptly.
- Protect IP that does not merit patent protection, but that provides key competitive advantages, as trade secrets.
- Disclose relevant IP to potential commercialization partners, protected under nondisclosure agreements.
- Determine which results are suitable for immediate propagation and perform technology transfer via conference presentations and publications. These include outcomes and methodological aspects that do not comprise IP.
- As patent applications are published by the USPTO, begin to write scholarly articles for publication in refereed journals.

12 Grand Forks, ND, June 19-21, 2011.

13 Fargo, ND, September 11-14, 2011.

14 Washington, DC, November 30 - December 1, 2011.

- Transfer the benefits of the new technology to the public by commercializing the technology.

3.2 Production Readiness Plan

A Production Readiness Plan specifies steps to commercialize the Menon Biofuel™ process. Nearly all steps of the baseline process have been proven out in the laboratory, and many of them have been specified at engineering scale. The Production Readiness Plan:

1. Develops and optimizes critical processes, equipment, and resources for boosting production through engineering scale to commercial scale;
2. Sources supplier technologies and identifies any unknowns, bottlenecks or capacity constraints;
3. Develops commercial-scale processes to handle any hazardous or non-recyclable materials;
4. Specifies an implementation program, including cost estimates for the proposed biofuel system, and ranges for investment threshold to launch the product;
5. Specifies a timeline to attain commercial-scale implementation.

The following Plan is subject to change without notice, based on Company, market, technology or other circumstances.

Menon has proceeded rapidly in implementing this Plan since the start of the program. Currently, the company is scaling up its Innovation Center, testing new pretreatment methods for cellulosic feedstock, and negotiating contracts to set up commercial plants at sites overseas. Menon has obtained long-term supply commitments for process feedstock (overseas) as well as expressions of interest to purchase TAG (domestically) and spent biomass as animal feed (both domestically and overseas). Up-take letters of interest are included in the Technology Transfer Plan.

3.2.1 The Menon Innovation Center

Menon has already obtained debt financing to fund development and installation of its Innovation Center, a facility enabling process development and optimization at engineering scale – that is, at a scale that can be directly transferred to commercial production. The first tranche of debt financing has been obtained via a Small Business Administration loan guarantee program that was part of the American Recovery and Reinvestment Act (ARRA). It funds the basic Innovation Center infrastructure and the first large-scale bioreactor system. Figure 14 is an aerial photograph of the Innovation Center site prior to the major construction. The Innovation Center will undergo commissioning and become operational in October 2011, with further development to follow. A second tranche of debt financing that will enable installation of an engineering-scale pretreatment and material handling facility and TAG extraction facility is in preparation.

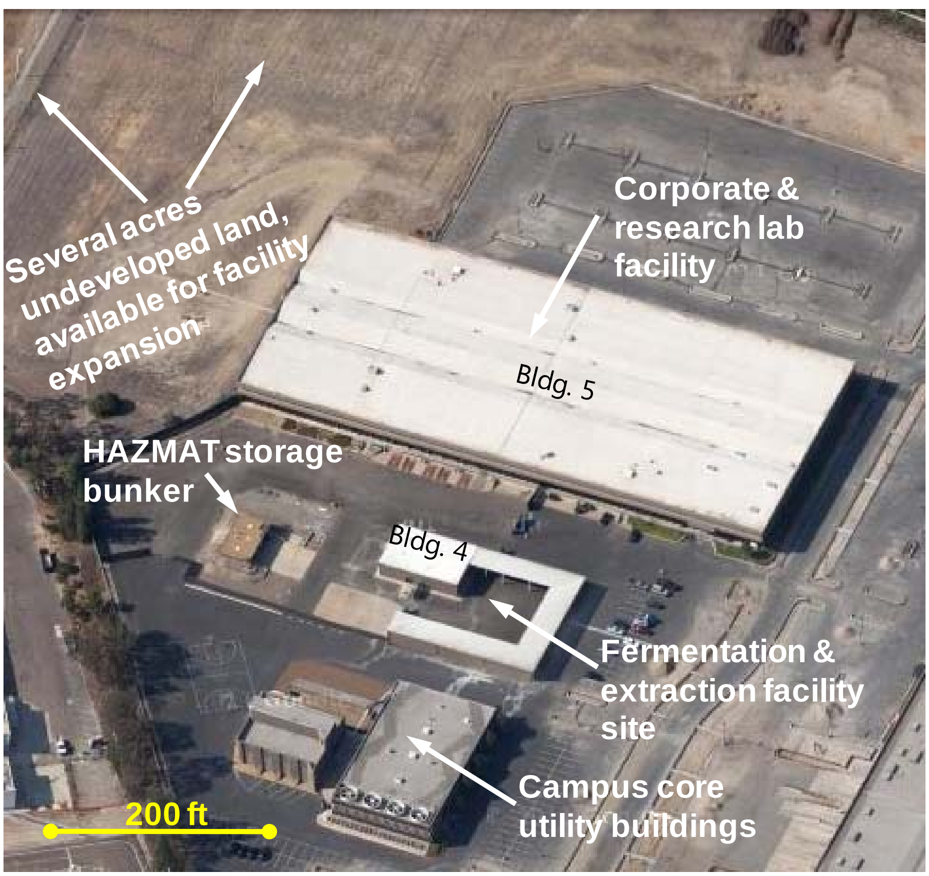
3.2.2 Scale-Up Development of Critical Production Processes and Equipment

The Production Readiness Plan must demonstrate feasibility and scale-up of all critical production processes necessary for a biofuel plant. Each critical production process has been or is being experimentally resolved in the Menon laboratory, and then re-engineered to commercial plant scale in the Innovation Center. In all cases, baseline methods and systems exist, and ongoing work seeks to improve them to lower cost in commercial production. Examples include:

1. Cellulose Pretreatment to Release Nutrients. Experiments, internally funded, are underway to demonstrate novel, lower-cost treatments to release sugars and other soluble organic molecules from cellulose. Advantages of the low-temperature processes are reduced energy consumption for lower cost, and reduced production of inhibitory compounds such as furfural.

2. Aeration. Menon is testing new technologies to provide optimal aeration of the fermentation broth. This requires determining the best compromise between different parameters. For example, one needs maximum oxygen dispersal through the culture medium (easiest with high mechanical agitation speeds) while exposing the microbes to minimal shear (which requires low agitation speed).

Figure 14: Menon Innovation Center Facility.



Following are critical equipment needs for the scale-up and commercialization of the new process. As above, baseline configurations exist and Production Readiness work will improve on that baseline to improve process productivity and reduce cost.

1. Material Handling for Pretreatment. Large quantities of cellulosic material will be stored, ground, processed for cellulose reduction, and prepared for fermentation. Automation and control are key features. In collaboration with an Engineering, Procurement and Construction (EPC) firm, Menon is sourcing the needed equipment.

2. Bioreactor Vessels. Bioreactors are central to the plant. Important design constraints include: ease of cleaning, guaranteed sterility when closed, uniform rapid temperature control, and uniform agitation shear and oxygen diffusion despite viscosity changes during fermentation. Menon has developed a large-scale bioreactor design with a manufacturer, modifying commercial designs to meet specific needs. Such efforts will continue as part of the Production Readiness Plan, using lessons learned during operation of the Innovation Center, to optimize the design while minimizing capital cost.

3. Biomass Drying. Automated, semi-continuous, energy-efficient drying systems adapted to the Menon biomass are currently in the design stage and will be tested in the coming months.

3.2.3 Critical Facilities

Facilities critical to the commercialization program are the Menon Innovation Center described above, baseline commercial plants overseas and, eventually, an initial California Biofuel Demonstration Plant test site.

The company is currently negotiating to install entry commercial plants at locations overseas, largely focused on the local animal feed market with biofuel as a co-product. Design and operation of these installations will provide valuable experience in scale-up engineering and agricultural waste processing, all directly applicable to the California program.

In parallel, we will work toward selecting and establishing a California Biofuel Demonstration Plant site. The plant will be located close to a cellulosic agricultural waste source (almond orchards or centralized almond hull processing facilities, for example) as well as water, power, transportation, and other facility needs. The process includes identifying and obtaining all permits needed to enable plant operation.

3.2.4 Critical Personnel Resources

The Innovation Center's first large-scale fermentation tank will come online before the end of 2011. As the development program then ramps up, the staff at the Center is expected to nearly double in the next year to support expanded laboratory experimentation and the greatly increased flow of fermentation products from large batch runs. Primary staff needs include chemical and biological process engineers and operations support staff.

Efforts toward a California Biofuel Demonstration Plant are expected to begin by mid-2013. A field operations team will be assembled and trained (led by the experienced Menon development team, and expanded with new engineering hires) to support technology transfer and assist in the new process. Thereafter, the Innovation Center will continue to provide technology assistance, feedstock testing, and the proprietary inoculum for Menon fermentation.

3.2.5 Obtaining Cellulosic Feedstock

Since the process is intended to draw on low-value materials and since the energy density of cellulosic material is relatively low, transportation costs for delivering the materials are an important factor. Therefore a California Biofuel Demonstration Plant should be located near an accumulation site for the feedstock materials, such as an almond hulling site. The advantage of a centralized site will be that all costs involved in transporting to the site are already covered, so that any additional costs involved in transporting the hulls to the Demonstration Plant will be minimal. As part of Production Readiness activity, Menon will be negotiating feedstock sourcing agreements analogous to those already concluded for its initial overseas plants.

Biodiesel manufacturers have expressed willingness to sell their waste glycerol to Menon as a feedstock; this will help smooth out seasonal fluctuations in the supply of cellulosic material. Animal wastes such as cattle manure, under investigation under a separately funded program, also offer the same capability to smooth out seasonal supply fluctuations.

3.2.6 Sourcing Critical Supplier Technologies

Suppliers for all of the Innovation Center capital items have been identified and vetted. Some of the same suppliers can be used for the Demonstration Plant program, although we are actively pursuing a range of options regarding the large fermentation tanks. Alternative suppliers will also be considered for the heaters, oxygen generators, and other large items as the Demonstration Plant design proceeds.

3.2.7 Supplier and Capacity Constraints

Development and implementation of the Demonstration Plant is not expected to be limited by manufacturing constraints, because multiple qualified companies are prepared to install fermentation tanks and the other equipment. In the near term, the schedule is expected to be controlled by the development program, since a significant number of process parameters must be optimized and then tested for scale-up, all using the Innovation Center facility. Importantly, a wide variety of California and other feedstocks will be tested, particularly for preprocessing (cellulose breakdown) issues which are often feedstock material-dependent.

The speed of obtaining financing is another constraint. In the medium term, as the first Demonstration Plant comes on line and subsequent plants are installed, the pacing items are again expected to be market-related, rather than limited by any equipment manufacturing constraints.

3.2.8 Handling Materials And Effluents

A California Biofuel Demonstration Plant must have fully engineered, fully compliant means to handle all materials entering and exiting the plant. These include the following:

- Incoming cellulosic feedstock;
- Culture media components;

- Resulting microbial biomass;
- Chemical solvents used to extract TAG, including means to recapture and recycle essentially all of them;
- Treatment of used culture media, including means to recapture and reuse as much of the water as possible, and treat the remainder to meet effluent environmental standards;
- Catalysts, solvents and wastes associated with the conversion of TAG to biofuels, if that is to be done on-site.

Each of these design critical issues is being worked on in the Innovation Center. Baseline approaches have been identified and tested on a small scale, with engineering-scale implementation and testing to take place when the large-scale systems come on line.

The process involves the following hazardous materials: potassium hydroxide, methanol, and organic solvents. All of these materials are either consumed in the process chemistry or recycled (99.9 percent capture or higher anticipated). Ultimate effluents include CO_2 (from the fermentation process and from on-site power generation), possibly NO_X (if on-site power is generated via combustion), small amounts of VOC (volatile organic compounds, primarily solvent escape), and small amounts of non-hazardous solid waste.

3.2.9 Proof-of-Production-Process

The Innovation Center will be used for a Proof-of-Production-Process feasibility test of the Menon Biofuels™ process prior to construction of the California Biofuel Demonstration Plant. The process will be demonstrated at large scale with full fermentation process control and automation in material handling/harvesting/drying. The demonstration will generate cellulosic biofuel as the final product, and will also generate saleable animal feed and aquaculture feed as co-products. The Proof-of-Production-Process will serve as the experience basis for implementing the Menon process at the Demonstration Plant scale. Additional proof-of-production-process experience will be afforded by overseas baseline commercial plants.

3.2.10 Projected Costs

ROM costs are estimated for R&D at the Innovation Center, and development of the California Biofuel Demonstration Plant. The Innovation Center is responsible for laboratory experimentation to establish feasibility of processes and to optimize parameters such as aeration. The Innovation Center also performs the initial scale-up engineering and testing. An important function of the Innovation Center will continue to be testing various California agricultural feedstock materials and assisting in the testing of our products for fish/animal feed. The estimated Innovation Center budget will be $3M/yr for the coming years.

The California Biofuel Demonstration Plant has been tentatively scaled as a 2.5 MGal/year biofuel producer, sited in the Central Valley near accumulation points for low-value cellulosic material such as almond hulls. The sites under consideration are also not far from customers receiving the animal feed byproducts. Options have been studied for producing the biofuel on-site or for selling TAG directly. Such a plant involves a capital investment of about $27M over a 2-year period. That figure includes first-plant contingencies and start-up costs in addition to capital expenses, and it is anticipated that subsequent plants will cost less, based on lessons learned. We assume that the Plant schedule begins immediately upon the successful Proof-of-Production-Process. The Demonstration Plant is expected to become operational in year 2 and achieve positive margin in its year 3.

3.2.11 Investment Threshold to Launch

The Menon plan assumes funding from a combination of Federal, State, private-sector and internal company sources for Innovation Center experimentation and feedstock-specific pretreatment and scale-up studies leading to the Proof-of-Production-Process. Federal funding may be obtained via competitive awards from the U.S. Departments of Energy, Agriculture and Defense and the National Science Foundation. Proposals have been submitted or are in preparation for all of the above. Similarly, Menon plans to submit proposals for further support to the California Energy Commission. Funding from any of these sources is not assured.

Positive results from the Proof-of-Production-Process test, coupled with a solid commercialization plan and validated engineering design for the California Biofuel Demonstration Plant, will motivate private (institutional) investment needed for the first plant. Further funding for installation and startup of subsequent plants may be derived from private or public investment.

3.2.12 Implementation Plan

The overall plan is to perform experimental feasibility testing and initial scale-up engineering studies at the Innovation Center, followed by the California Biofuel Demonstration Plant, followed by construction of several biofuel plants across the US agricultural corridor. In parallel, a series of greenwaste-to-animal-feed plants (possibly also generating biofuel) are planned at sites overseas.

A proposed Phase 2 CA PIER program will be dedicated to improving the baseline process for selected California feedstocks. Results of these tests will be demonstrated at large scale. The program will conclude with a Proof-of-Production-Process demonstration, tentatively planned for 2013, although it could happen sooner. In the event that PIER funding is not available, resources for the work will be sought from Federal or private-sector sources.

Assuming technical success and success in obtaining the necessary investment funding, construction of the California Biofuel Demonstration Plant will take the next 2 years, including 6 months of startup and testing. Full commercial biofuel production is planned for year 3.

In parallel with the potential CA PIER and Demonstration Plant activities, the company plans to implement a plant, at an overseas site to be determined, aimed primarily at the animal feed market. This plant and the Demonstration Plant will complement each other by providing mutual engineering solutions, improved economy in certain capital items, and continuing operational experience which benefits both programs.

The Innovation Center will continue to provide technical support throughout the program. The Innovation Center will also supply the proprietary inoculum for all of the fermentation sites using the Menon process.

3.2.13 Production Readiness Plan Timeline

The following chart presents a provisional timeline for executing the Production Readiness Plan through operation of the California Biofuel Demonstration Plant. It includes a proposed Phase 2 program under California PIER funding, with a two-year period of performance spanning 2012 and 2013; in the event that such support is not forthcoming, other funding sources will be sought, with a resulting slip in schedule.

Table 5: Provisional Top-Level Timeline for Menon Production Readiness Plan

Activity	2011	2012				2013				2014	2015	2016
	4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q			
Innovation Center commissioning												
Scale-up process development & optimization												
CA PIER Phase 2: CA feedstock pretreatment optimization												
CA PIER Phase 2: Product evaluation & scale-up productivity demo												
Financing for overseas												
Vendor sourcing												
Overseas Plant 1 design & construction												
Overseas Plant 1 operation												
CA Biofuel Demo Plant financing												
CA Biofuel Demo Plant design & permitting												
CA Biofuel Demo Plant construction												
CA Biofuel Demo Plant operation												

Note that if the proposed PIER Phase 2 effort is not funded, the work will likely be funded from other sources.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The project had several key outcomes. Menon demonstrated that almond hulls and grape pomace make viable feedstocks, and showed the need for pretreatment to deploymerize the cellulose and hemicellulose into readily accessible sugars. Menon converted its TAG into biodiesel that meets ASTM D6751 specifications for biodiesel fuel. Menon developed an economic model showing that with appropriate pretreatment, almond hulls and grape pomace can become economically viable sources of biofuel at scales of several hundred acres and higher. Menon validated that when the biofuel plant power is provided from non-fossil sources, the net year-on-year GHG emissions are zero, since the process and later fuel consumption recycle carbon dioxide into the air that had been sequestered from it in the preceding year. Menon has developed a Production Readiness Plan for its technology and is already implementing it.

During the course of the project, Menon's commercialization plan also evolved. The project as conceived and executed focused on small-scale biofuel production on individual farms, using the farm's own waste to make the fuel needed for farm operations (and selling the rest, along with co-products). At the start of this project, Menon planned to license its technology and distribute it, along with detailed plant designs, to farm operations that would operate the plants. For this reason, the process to upgrade TAG to fuel had to be simple and safe, dictating a focus on biodiesel.

As Menon has matured its technology and its market awareness during the course of the project, Menon's business model has shifted to constructing and operating commercial-scale plants to manufacture biofuel and co-products. The reasons for this are basically twofold. First, unit production costs decline as production scale increases, making larger plants more profitable (and generating more economic return to the state). Second, commercial-scale plants enable production of fuel that is superior to biodiesel, being fully compatible with the transport, distribution and use infrastructure already in place for petroleum-based fuels.

4.2 Recommendations

Menon recommends the following steps toward rapid commercial deployment of biofuel technology in California.

- Working with the Energy Commission-funded database and model developed under the direction of Dr. S.R. Kaffka, University of California at Davis, identify the two crops yielding agricultural residues with (a) the highest potential fuel yield per acre, (b) the region(s) with the most geographically concentrated production, to minimize feedstock transportation, and (c) yielding the greatest differential economic benefit compared to present-day methods of waste disposition. These should then become the focus of subsequent activity.

- Working with feedstock pretreatment researcher Dr. C.E. Wyman at University of California, Riverside, optimize pretreatment processes for each selected feedstock to minimize the cost of pretreatment per unit lipids and co-products produced. (Differences from one feedstock to the next make the optimum process settings feedstock-dependent.)
- Optimizing microbial culture parameters for each selected feedstock and demonstrate production at engineering scale.
- Converting the resulting lipids to a renewable diesel fuel meeting the ASTM D975 specification for diesel transportation fuels. This would demonstrate fungibility with petroleum-derived diesel fuels.
- Conducting animal feed trials with the microbial biomass after lipid extraction to confirm the high value (≥$1,000/ton) of the animal feed ingredient co-product.

These activities, together with Menon's concurrent process development and commercialization activities, can lead to a California Biofuel Demonstration Plant operating profitably, within two years of completion of the above activities. It would mark the start of a commercial industry that uses non-food feedstock to make petroleum-fungible fuels and an animal feed co-product, thereby reducing California's dependence on foreign oil, reducing its greenhouse gas emissions, eliminating the competition between food and fuel associated with grain-derived ethanol, alleviating food shortage concerns, and creating new California jobs in green technology.

GLOSSARY

$M	Millions of dollars.
Almond hull	Almond nuts are seeds surrounded by a hard shell, inside a fruit body that is called the hull.
ASTM	American Society for Testing and Materials.
ASTM D6751	A set of specifications and testing procedures developed and accepted for biodiesel as a transportation fuel.
Biodiesel	A renewable fuel often made from vegetable oil; chemically, they are esters of fatty acids; practically, the important distinction between biodiesel and petroleum-based diesel fuel is that biodiesel molecules contain oxygen whereas conventional diesel (and gasoline) molecules do not. This makes the amount of energy per gallon of biodiesel less than that of diesel, and also allows biodiesel to go rancid in storage, if not used soon enough.
CA	California.
CAAFI	Commercial Aviation Alternative Fuels Initiative.
Cellulose	A major structural component of plant matter, cellulose is a polymer of sugar molecules each containing six carbon atoms (like glucose).
Cellulosic	Containing cellulose and hemicellulose; often used as a shorthand to distinguish the structural component of plants from the seed, legume or tuber component that usually contains starch and often forms the principal human food product.
CH_4	Methane.
CO_2	Carbon dioxide.
Depolymerization	The process of breaking up a polymer material into its individual components; in the case of cellulose, the individual components are sugar molecules containing six carbons each.
Diesel	A fuel usually produced from fossil petroleum, containing only hydrocarbon molecules (apart from minute quantities of additive compounds).
Energy Commission	California Energy Commission.
EPC	Engineering, Procurement and Construction.
Ester	An organic molecule obtained by reacting an acid incorporating a carboxyl group (COOH) with an alcohol; esters made from fatty acids form the main constituents of biodiesel.

FAME	Fatty acid methyl ester, the main constituent of biodiesel.
Fatty acid	An organic molecule with a chain of carbon and hydrogen atoms terminating in a carboxyl acid group (COOH). The chain is the "fat" part that stores chemical energy, and the carboxyl group makes it an acid.
Furfural	An organic compound that is a byproduct of cellulose depolymerization reactions under certain conditions; it tends to inhibit microbial growth and activity, making it undesirable in fermentation-based biofuel processes.
gal	Gallon.
GHG	Greenhouse gas.
Greenhouse gas	Any gas that, once released into the atmosphere, helps convert solar radiation into heat and trap it in the atmosphere. Examples include carbon dioxide (CO_2) and methane (CH_4).
Hemicellulose	A major structural component of plant matter, hemicellulose is a polymer of sugar molecules each containing five carbon atoms (like xylose).
Hydrolysis	The specific chemical reaction that breaks sugar polymers into their individual sugar constituents. The term refers to the fact that water (H_2O) is broken into two ions, H^+ and OH^-, in a hydrolysis step during the reaction.
Hydrocarbons	Molecules that contain nothing except carbon and hydrogen; they are the major constituents of fuels made from fossil petroleum.
Hydrolyzate	The product of a hydrolysis reaction; in this context, the sugars produced by hydrolysis of cellulose or hemicellulose.
Inoculum	The initial dose of microbes used to inoculate, or seed, a microbial culture.
IP	Intellectual Property.
kg.	Kilogram.
L	Liter.
Lignin	A major structural component of plant matter, lignin (from the Greek word for wood) is a biopolymer that lends stiffness to the structure. It encases the cellulose and must be degraded to enable access to the sugar content of the cellulose.
Lignocellulose	Plant matter incorporating lignin, cellulose and hemicellulose.

Linoleic acid	A fatty acid with 18 carbon atoms in a chain and two double bonds (a so-called di-unsaturated fatty acid, since hydrogen atoms are “missing” from two locations).
Mgal	Millions of gallons.
mt.	Metric ton.
NO_X	Nitrogen oxides (both nitric oxide and nitrous oxide).
Oleic acid.	A fatty acid with 18 carbon atoms in a chain and one double bond (a so-called mono-unsaturated fatty acid, since a hydrogen atom is “missing” from one location).
Palmitic acid	A fatty acid with 16 carbon atoms in a chain and no double bonds, so that all possible sites are occupied by hydrogen atoms (this is what is meant by a fully saturated fatty acid).
Petroleum	The raw material, of fossil origin, that is converted into hydrocarbon fuels like diesel, gasoline and jet fuel, as well as an array of specialty organic chemicals.
pH	The measure of the acidity or basicity of an aqueous solution.
PIER	Public Interest Energy Research.
Pomace	The remaining skin and pulp of fruit from which the juice has been squeezed.
R&D	Research and Development.
Renewable diesel	Diesel fuel, consisting of hydrocarbons and chemically equivalent to diesel from petroleum, but which is made from a renewable, non-fossil feedstock.
Saccharification	The process of converting cellulose and/or hemicellulose into its constituent sugars.
SO_2	Sulfur dioxide.
Stearic acid	A fatty acid with 18 carbon atoms in a chain and no double bonds, so that all possible sites are occupied by hydrogen atoms (this is what is meant by a fully saturated fatty acid).
TAG	Triacylglyceride (q.v.).
Transesterification	The chemical reaction that converts fatty acids, usually bound to a glycerol backbone, into esters such as the constituents of biodiesel.
Triacylglycerid	An organic molecule comprising three fatty acids bound to a single glycerol backbone; the structure of most vegetable oils.
USDA	United States Department of Agriculture.

USPTO	United States Patent and Trademark Office.
VOC	Volatile Organic Compounds.